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Dumitru et al.

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(54) **TOUCH SENSOR AND METHODS OF MAKING SAME**

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(22) Filed: **Jul. 16, 2014**

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(51) **Int. Cl.**

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G06F 3/041	(2006.01)
G06F 3/044	(2006.01)
G06F 3/0354	(2013.01)

(52) **U.S. Cl.**

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(58) **Field of Classification Search**

CPC G06F 3/0412
USPC 345/174
See application file for complete search history.

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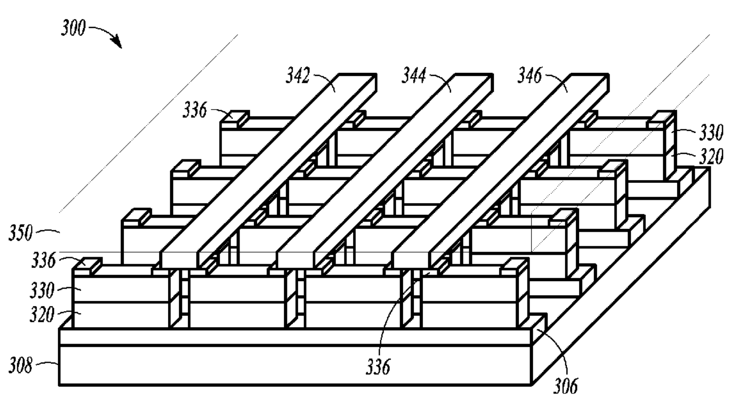
(57) **ABSTRACT**

The present disclosure relates to a touch sensor and touch sensitive display having a plurality of first and second conductive lines arranged substantially orthogonally with a sensing material to sense a change in capacitance between them. The first and second conductive lines and the sensing material defining an array of sensitive transistors.

14 Claims, 8 Drawing Sheets



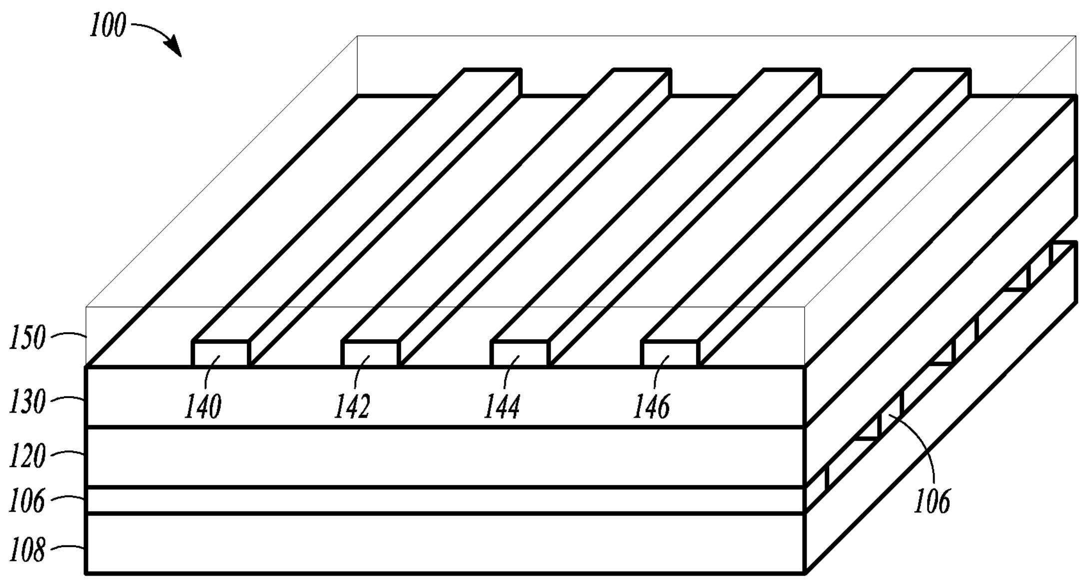

100
150
130
120
106
108
140
142
144
146
106

FIG. 1A

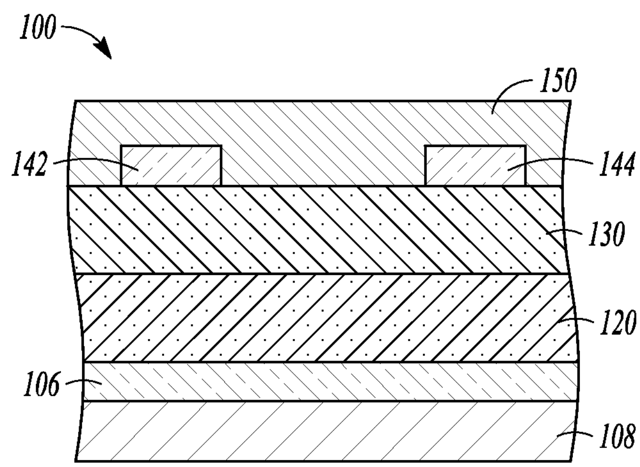

100
150
142
144
130
120
106
108

FIG. 1B

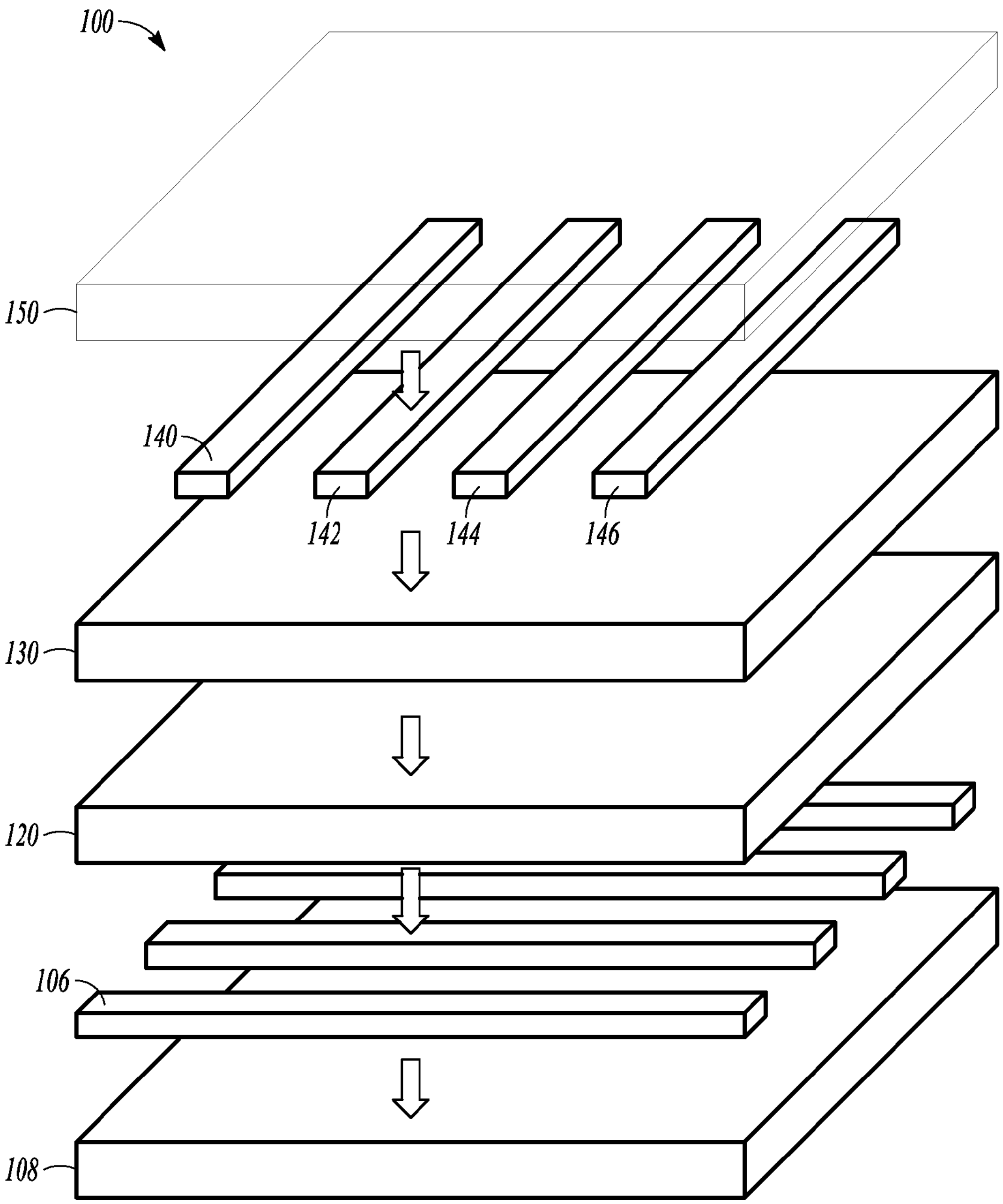


FIG. 2

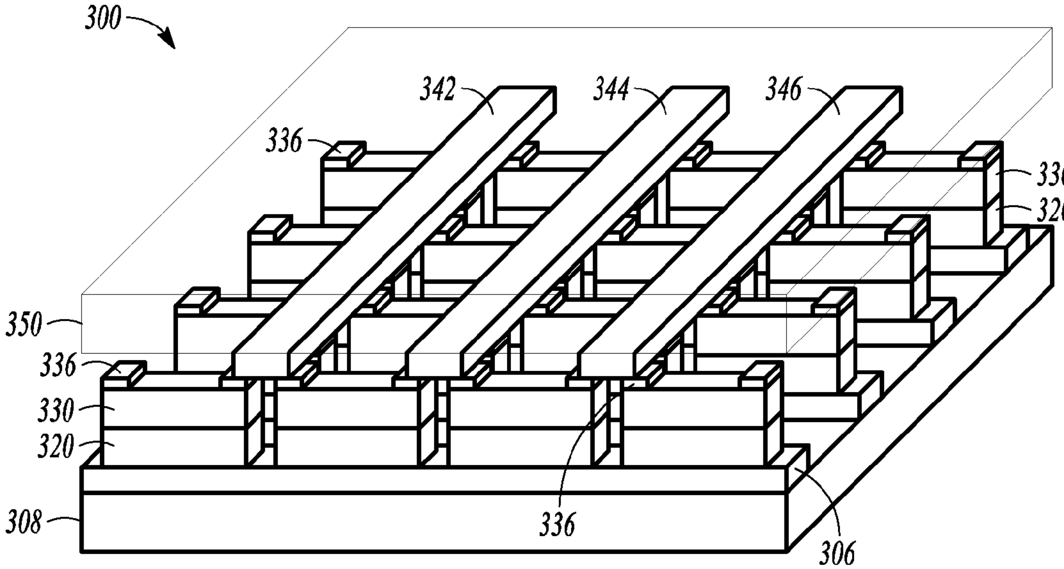

300
342
344
346
336
330
320
350
336
330
320
308
336
306

FIG. 3A

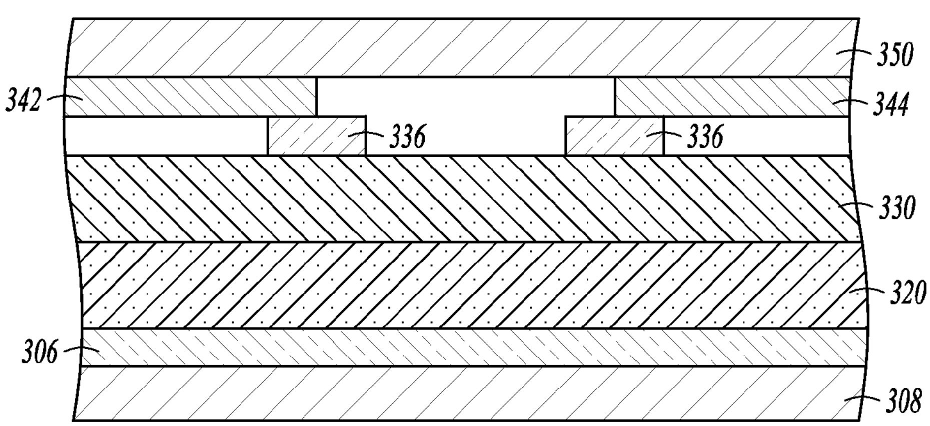

350
342
344
336
336
330
320
306
308

FIG. 3B

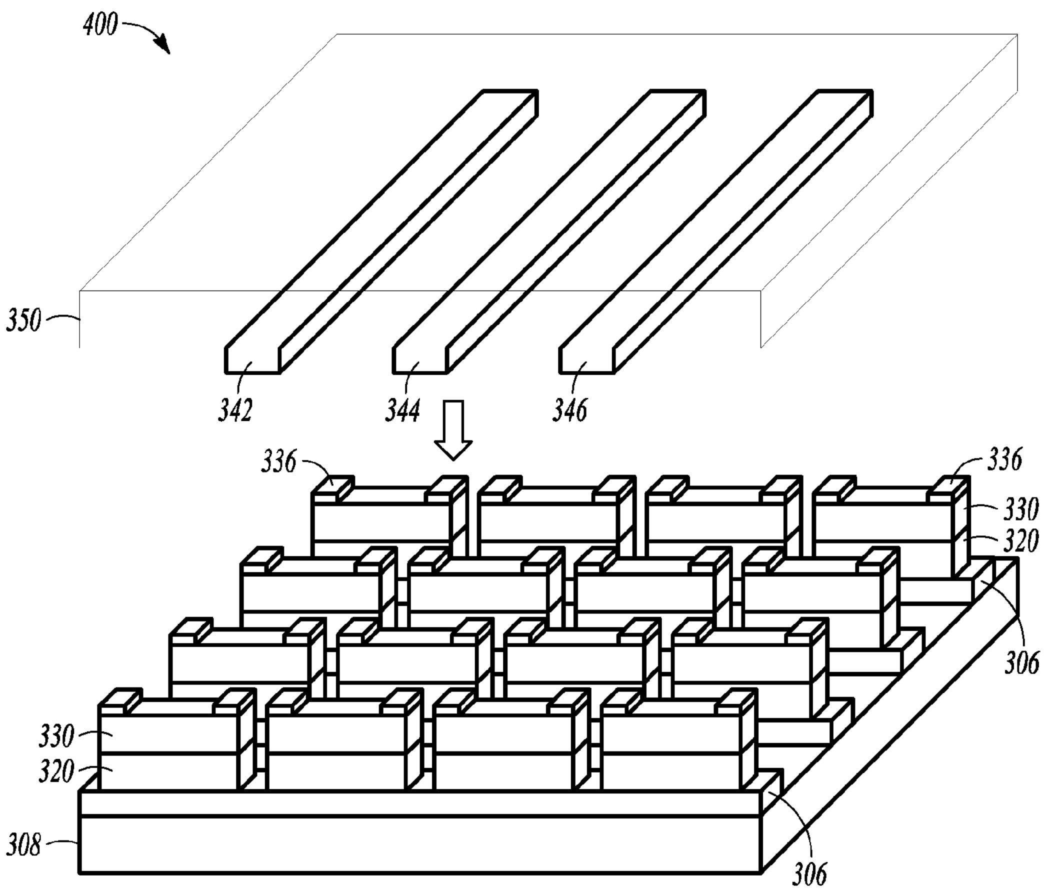


FIG. 4

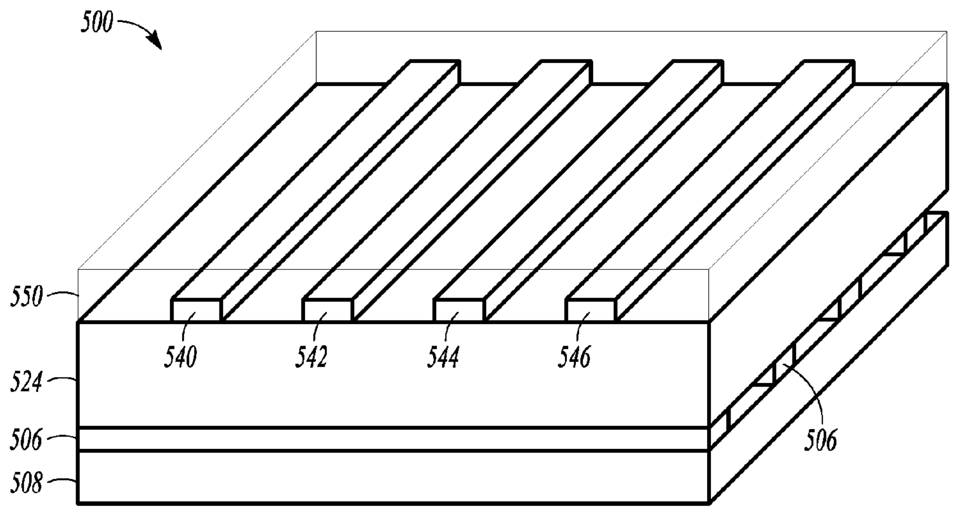

500
550
524
506
508
540
542
544
546
506

FIG. 5A

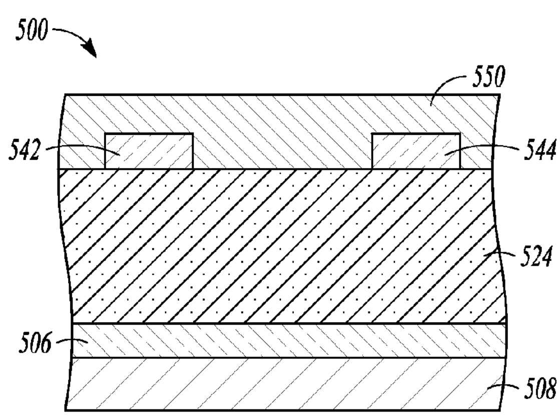

500
550
542
544
524
506
508

FIG. 5B

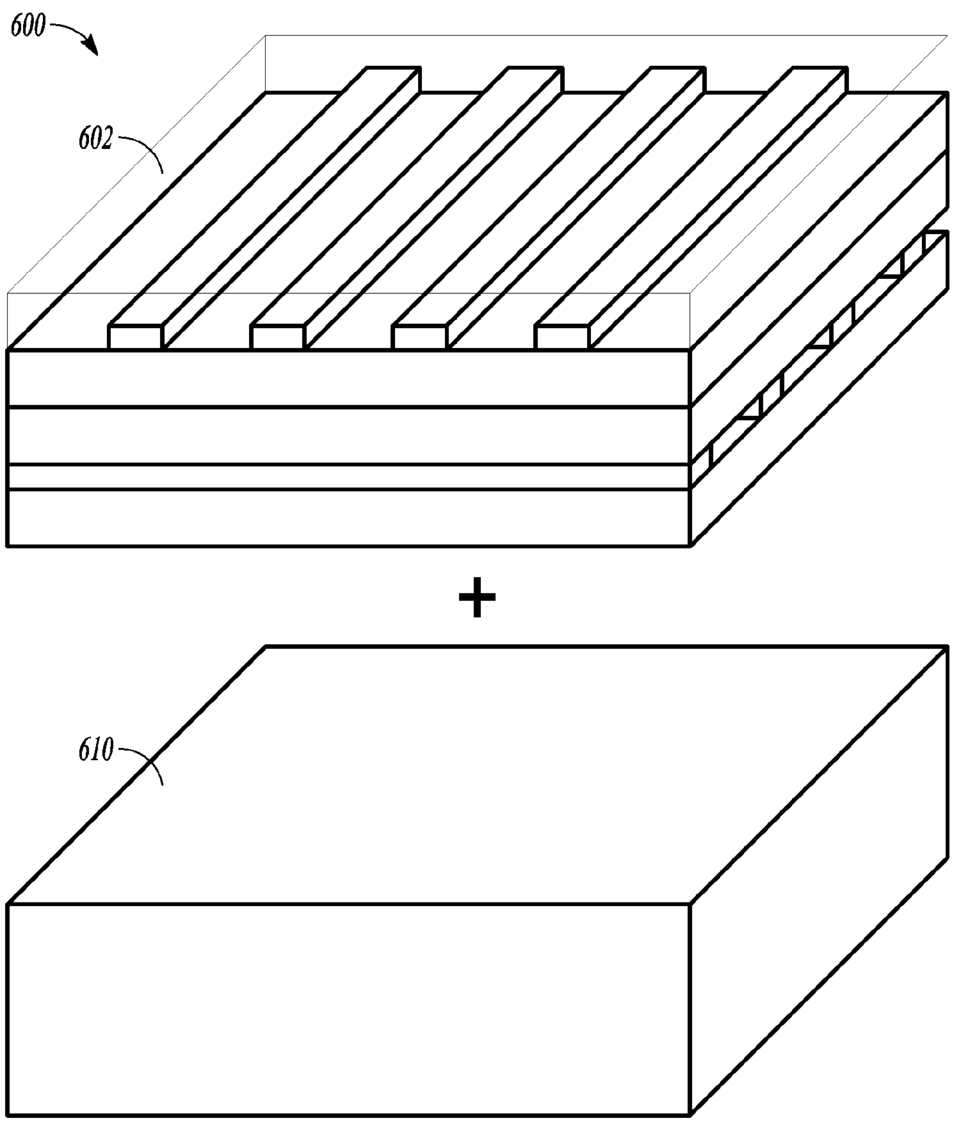


FIG. 6

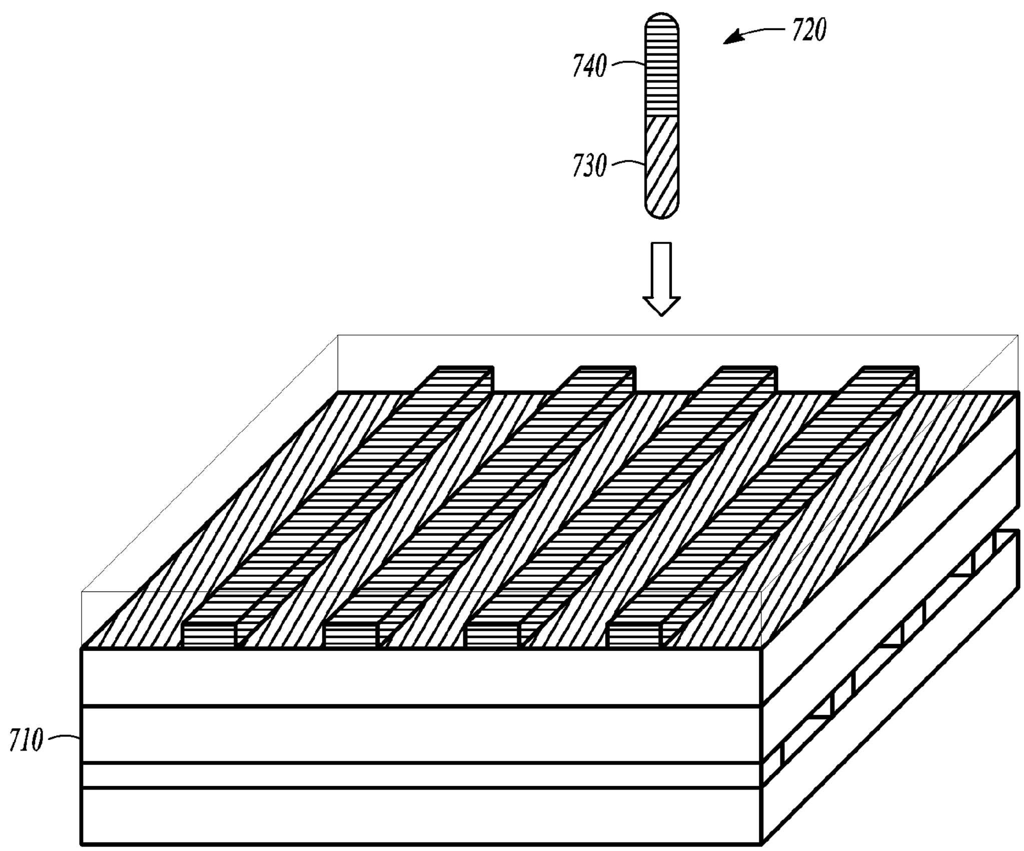


FIG. 7

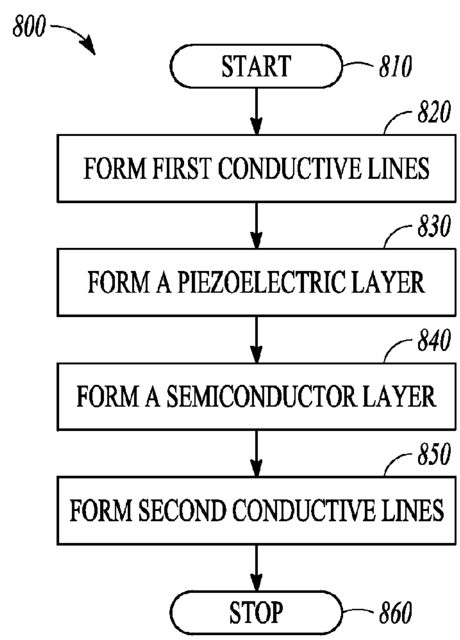

800
START
810
820
FORM FIRST CONDUCTIVE LINES
830
FORM A PIEZOELECTRIC LAYER
840
FORM A SEMICONDUCTOR LAYER
850
FORM SECOND CONDUCTIVE LINES
STOP
860

FIG. 8

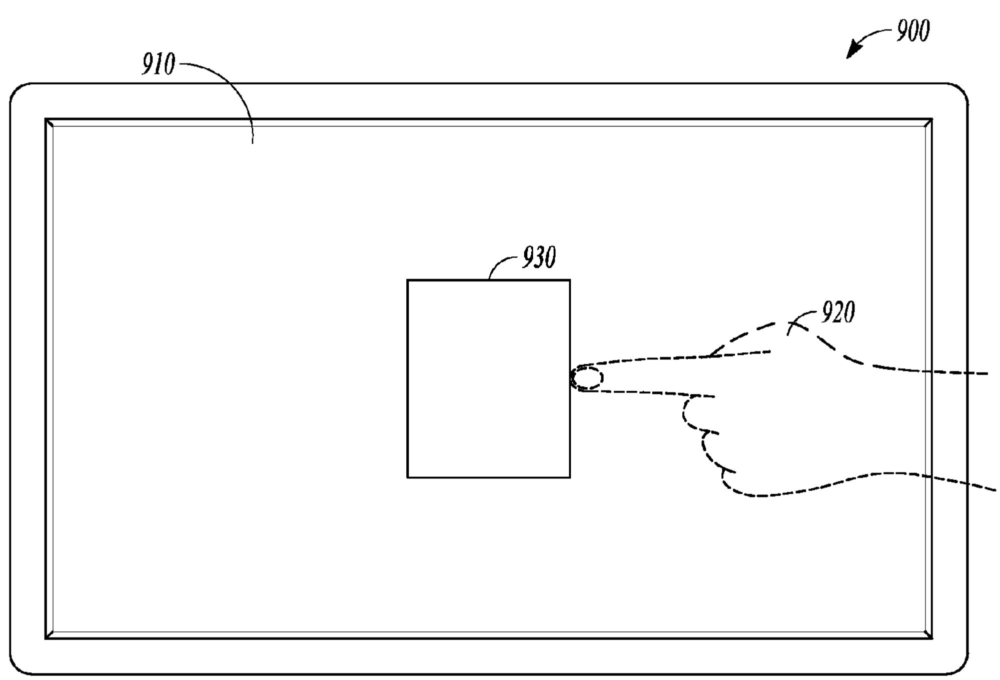

900
910
930
920

FIG. 9

TOUCH SENSOR AND METHODS OF MAKING SAME

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority under 35 U.S.C. Section 119 to European Patent Application Serial No. 13176756.8, filed on Jul. 16, 2013, which application is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present disclosure relates to touch sensors and methods for making same. More particularly, the disclosure relates to a touch sensor that utilizes semiconductor and piezoelectric materials.

BACKGROUND

Touch sensors are a component of touch-sensitive displays that are widely used in smart phones, tablet computers and portable game machines. Existing touch sensors may be based on resistive, capacitive, acoustic or optical touch sensing technologies. Each of these technologies have limitations such as, for example, no or limited multi-touch capabilities, limited sensitivity, complicated detection algorithms or a lack of user-friendliness.

There is therefore a need in the art for touch sensors that do not suffer from some of these drawbacks. The embodiments of the present invention address this need.

SUMMARY

A touch sensor includes first conductive lines, second conductive lines, and a sensing material between the first conductive lines and the second conductive lines to sense a change in capacitance between the first conductive lines and the second conductive lines and to sense a force applied to the sensing material.

A method includes forming first conductive lines, forming second conductive lines, and forming a sensing material between the first conductive lines and the second conductive lines, the sensing material to sense a force applied to the sensing material and to sense a change in capacitance between the first conductive lines and the second conductive lines.

In still another embodiment, a touch-sensitive display includes a display and a touch sensor in the display, the touch sensor including first conductive lines, second conductive lines, and a sensing material between the first conductive lines and the second conductive lines, the sensing material to sense a force applied to the sensing material and to sense a change in capacitance between the first conductive lines and the second conductive lines.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is an oblique view of a touch sensor according to an example embodiment.

FIG. **1**B is a front view of a portion of the example touch sensor of FIG. **1**A according to an example embodiment.

FIG. **2** is an exploded view of the example touch sensor of FIG. **1**A according to an example embodiment.

FIG. **3**A is an oblique view of a touch sensor according to an example embodiment.

FIG. **3**B is a front view of a portion of the example touch sensor of FIG. **3**A according to an example embodiment.

FIG. **4** is an exploded view of the example touch sensor of FIG. **3**A according to an example embodiment.

FIG. **5**A is an oblique view of a touch sensor according to an example embodiment.

FIG. **5**B is a front view of a portion of the example touch sensor of FIG. **5**A according to an example embodiment.

FIG. **6** is an exploded view of a touchscreen according to an example embodiment.

FIG. **7** is an oblique view of a touch sensor and a pen according to an example embodiment.

FIG. **8** is a flowchart illustrating a method of forming the example touch sensor of FIG. **1**A according to an example embodiment.

FIG. **9** is a top view of an electronic device with a touch-sensitive display according to an example embodiment.

DETAILED DESCRIPTION

In the following description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present invention. The following description of example embodiments is, therefore, not to be taken in a limited sense, and the scope of the present invention is defined by the appended claims.

FIG. **1**A is an oblique view of a touch sensor indicated generally at **100** according to an example embodiment. A number of first conductive traces or lines **106** may be formed on a substrate **108** in a first direction. A piezoelectric layer **120** may be formed on the first conductive lines **106** and a semiconductor layer **130** may be formed on the piezoelectric layer **120**. A number of second conductive traces or lines **140**, **142**, **144** and **146** may be formed over the semiconductor layer **130** in a second direction that is substantially orthogonal to the first direction. The first conductive lines **106** and the second conductive lines **140**, **142**, **144** and **146** can form a grid of conductive lines when viewed from the top of the touch sensor **100**. A dielectric layer **150** may be formed over the second conductive lines **140**, **142**, **144** and **146** and the semiconductor layer **130**.

A location of a conductor (such as a human finger) near the first conductive lines **106** or the second conductive lines **140**, **142**, **144** and **146** may be sensed when current is flowing through the lines **106**, **140**, **142**, **144** and **146**. The conductor changes a capacitance between one of the first conductive lines **106** and one of the second conductive lines **140**, **142**, **144** and **146** which may be sensed by sense circuitry (not shown). The grid of the first conductive lines **106** and the second conductive lines **140**, **142**, **144** and **146** defines an array of sensitive transistors.

The piezoelectric layer **120** can sense an applied force. When stressed by a force applied to the touch sensor **100**, the piezoelectric layer **120** generates electric charge that modulates the current flowing through the semiconductor layer **130** and the second conductive lines **140**, **142**, **144** and **146**. The modulated current can be sensed by the sense circuitry (not shown).

FIG. **1**B is a front view of a portion of the example touch sensor **100** of FIG. **1**A illustrating one of the transistors according to an example embodiment. The front view of FIG. **1**B includes one of the first conductive lines **106** that is a gate of a transistor. The second conductive line **142** is a source, the second conductive line **144** is a drain, and the semiconductor layer **130** is a channel of the transistor.

FIG. **2** is an exploded view of the example touch sensor **100** of FIG. **1**A according to an example embodiment to illustrate the formation of the touch sensor **100**. The first conductive lines **106** may be deposited on the substrate **108** which is transparent. The substrate **108** may comprise indium tin oxide over polyethylene terephthalate (ITOPET). The first conductive lines **106** may be obtained by patterning the indium tin oxide (ITO) in the ITOPET.

The piezoelectric layer **120** may be transparent and comprise AlN deposited by sputtering. The semiconductor layer **130** may be transparent and comprise ZnO, InGaZnO, Al(x)In(1−x)N or thin InN deposited by sputtering. The semiconductor layer **130** may also comprise carbon nanotubes or nanowires formed by printing. The second conductive lines **140**, **142**, **144** and **146** may be deposited on the semiconductor layer **130** and the dielectric layer **150** may be formed over the second conductive lines **140**, **142**, **144** and **146** and the semiconductor layer **130**. The second conductive lines **140**, **142**, **144** and **146** may comprise ITO and the dielectric layer **150** may comprise silicon dioxide.

FIG. **3**A is an oblique view of a touch sensor indicated generally at **300** according to an example embodiment. A number of first conductive traces or lines **306** may be formed on a substrate **308** in a first direction. A number of blocks of piezoelectric material **320** may be formed on the first conductive lines **306** and a block of semiconductor material **330** may be formed on each respective block of piezoelectric material **320**. Two electrical contacts **336** may be formed on each of the blocks of semiconductor material **330**, one at each end of each block of semiconductor material **330**. A number of second conductive traces or lines **342**, **344** and **346** may be formed over the blocks of semiconductor material **330** in a second direction that is substantially orthogonal to the first direction. The first conductive lines **306** and the second conductive lines **342**, **344** and **346** can form a grid of conductive lines when viewed from the top of the touch sensor **300**. A dielectric layer **350** may be formed over the second conductive lines **342**, **344** and **346** and the blocks of semiconductor material **330**.

In a manner analogous to the operation of the touch sensor **100** described above, a location of a conductor (such as a human finger) near the first conductive lines **306** or the second conductive lines **342**, **344** and **346** may be sensed. The conductor changes a capacitance between one of the first conductive lines **306** and one of the second conductive lines **342**, **344** and **346** which may be sensed by sense circuitry (not shown) when current is flowing through the lines **306**, **342**, **344** and **346**. The grid of the first conductive lines **306** and the second conductive lines **342**, **344** and **346** can define an array of sensitive transistors in the touch sensor **300**.

The blocks of piezoelectric material **320** can sense an applied force. When stressed by a force applied to the touch sensor **300**, the closest block of piezoelectric material **320** generates electric charge that modulates the current flowing through the block of semiconductor material **330** above the block of piezoelectric material **320** and the nearby pair of second conductive lines **342**, **344** and **346**. The modulated current can be sensed by the sense circuitry (not shown).

FIG. **3**B is a front view of a portion of the example touch sensor **300** of FIG. **3**A illustrating one of the transistors according to an example embodiment. The front view of FIG. **3**B includes one of the first conductive lines **306** that is a gate of a transistor. The second conductive line **342** is a source that is electrically coupled to the block of semiconductor material **330** through a first one of the electrical contacts **336**. The second conductive line **344** is a drain that is electrically coupled to the block of semiconductor material **330** through a second one of the electrical contacts **336**. The block of semiconductor material **330** is a channel of the transistor. The transistors in the touch sensor **300** are physically separated from each other in contrast to the transistors in the example touch sensor **100** of FIG. **1**A.

FIG. **4** is an exploded view of the example touch sensor **300** of FIG. **3**A according to an example embodiment to illustrate the formation of the touch sensor **300**. The first conductive lines **306** may be deposited on the substrate **308** which is transparent. The substrate **308** may comprise ITOPET. The first conductive lines **306** may be obtained by patterning the ITO.

The blocks of piezoelectric material **320** may be transparent and comprise MN. The blocks of semiconductor material **330** may be transparent and comprise ZnO, InGaZnO, Al(x)In(1−x)N or thin InN. The blocks of piezoelectric material **320** and the blocks of semiconductor material **330** may be deposited by sputtering on selected areas of the first conductive lines **306** using a mask. The blocks of semiconductor material **330** may also comprise carbon nanotubes or nanowires formed by printing. The electrical contacts **336** are deposited on either end of each block of semiconductor material **330** using a mask.

The second conductive lines **342**, **344** and **346** may be pre-patterned on the dielectric layer **350**, and the dielectric layer **350** with the second conductive lines **342**, **344** and **346** may be bonded to the elements described above such that the second conductive lines **342**, **344** and **346** are in contact with the electrical contacts **336**. The dielectric layer **350** is located over the second conductive lines **342**, **344** and **346** and the blocks of semiconductor material **330**. The second conductive lines **342**, **344** and **346** may comprise ITO and the dielectric layer **350** may comprise silicon dioxide.

FIG. **5**A is an oblique view of a touch sensor indicated generally at **500** according to an example embodiment. A number of first conductive traces or lines **506** may be formed on a substrate **508** in a first direction. A combined layer **524** that has both piezoelectric and semiconductor properties may be formed on the first conductive lines **506**. A number of second conductive traces or lines **540**, **542**, **544** and **546** may be formed over the combined layer **524** in a second direction that is substantially orthogonal to the first direction. The first conductive lines **506** and the second conductive lines **540**, **542**, **544** and **546** can form a grid of conductive lines when viewed from the top of the touch sensor **500**. A dielectric layer **550** may be formed over the second conductive lines **540**, **542**, **544** and **546** and the combined layer **524**.

A location of a conductor (such as a human finger) near the first conductive lines **506** or the second conductive lines **540**, **542**, **544** and **546** may be sensed when current is flowing through the lines **506**, **540**, **542**, **544** and **546**. The conductor changes a capacitance between one of the first conductive lines **506** and one of the second conductive lines **540**, **542**, **544** and **546** which may be sensed by sense circuitry (not shown). The grid of the first conductive lines **506** and the second conductive lines **540**, **542**, **544** and **546** defines an array of sensitive transistors.

The combined layer **524** can sense an applied force. When stressed by a force applied to the touch sensor **500**, the combined layer **524** generates electric charge that modulates the current flowing through the first conductive lines **506** and the second conductive lines **540**, **542**, **544** and **546**. The modulated current can be sensed by the sense circuitry (not shown).

FIG. **5**B is a front view of a portion of the example touch sensor **500** of FIG. **5**A illustrating one of the transistors according to an example embodiment. The front view of FIG. **5**B includes one of the first conductive lines **506** that is a gate of a transistor. The second conductive line **542** is a source, the second conductive line **544** is a drain, and the combined layer **524** is a channel of the transistor.

The touch sensor **500** may be formed in a manner analogous to the formation of the touch sensor **100** described above with reference to FIG. **2**. Instead of forming the piezoelectric layer **120** and the semiconductor layer **130**, the combined layer **524** may be formed. The combined layer **524** may be transparent and may comprise ZnO, GaN, InN or AlInN that may be deposited by sputtering. The substrate **508** may comprise ITOPET. The first conductive lines **506** and the second conductive lines **540**, **542**, **544** and **546** may comprise ITO. The dielectric layer **150** may comprise silicon dioxide.

FIG. **6** is an exploded view of a touch-sensitive display indicated generally at **600** according to an example embodiment. A touch sensor **602** is located on a display **610**. The touch sensor **602** may be any one of the touch sensors **100**, **300** or **500** shown in the figures and described above. The display **610** may be a liquid-crystal display (LCD) or an organic light-emitting diode (OLED) display according to an example embodiment.

FIG. **7** is an oblique view of a touch sensor **710** and a pen indicated generally at **720** according to an example embodiment. The touch sensor **710** may be any one of the touch sensors **100**, **300** or **500** shown in the figures and described above that can detect two different control actions. The pen **720** may comprise a writing portion **730** and an erasing portion **740**. The writing portion **730** is electrically conductive and may be detected by capacitive sensing in the touch sensor **710**. The writing portion **730** may be used to write on a touch screen including the touch sensor **710**. The erasing portion **740** is an electrical insulator that may not be detected by capacitive sensing. The erasing portion **740** may be sharper and more rigid than the writing portion **730** and an application of the erasing portion **740** with force to the touch sensor **710** may be detected by piezoelectric sensing in the touch sensor **710**. The writing portion **730** may be used for writing, and the erasing portion **740** may be used for erasing. Alternatively, the writing portion **730** is an electrical insulator that may be used to write via the piezoelectric sensing and the erasing portion **740** is electrically conductive and may be used to erase via the capacitive sensing. Sense circuitry may distinguish between different levels of force applied to the touch sensor **710** by the pen **720** and trigger different functions in response. Alternatively, the pen **720** may be an electrical insulator that may be used to write via the piezoelectric sensing while an erase may be performed by a human finger or hand via the capacitive sensing.

FIG. **8** is a flowchart illustrating a method **800** of forming the example touch sensor **100** of FIG. **1**A according to an example embodiment. The method starts at **810**, and at **820** first conductive lines may be formed on a substrate in a first direction. The first conductive lines may be may be formed by patterning ITO. At **830**, a piezoelectric layer may be formed on the first conductive lines. The piezoelectric layer may comprise MN deposited by sputtering. At **840**, a semiconductor layer may be formed on the piezoelectric layer. The semiconductor layer may comprise ZnO, InGaZnO, Al(x)In(1−x)N or thin InN and may be deposited by sputtering. At **850**, second conductive lines may be formed on the semiconductor layer in a second direction that is substantially orthogonal to the first direction. The second conductive lines may comprise ITO deposited on the semiconductor layer. A dielectric layer may be formed over the second conductive lines and the semiconductor layer. The dielectric layer may comprise silicon dioxide. The method ends at **860**.

FIG. **9** is a top view of an electronic device **900** with a touch-sensitive display **910** according to an example embodiment. The touch-sensitive display **910** may include any one of the touch sensors **100**, **300** or **500** shown in the figures and described above. The touch-sensitive display **910** may display information including, but not limited to, text, images and videos. A hand **920** or a finger on the hand **920** may be sensed by the touch-sensitive display **910** near an image **930**. The electronic device **900** may be a smartphone or a tablet computer.

Embodiments of the invention described and claimed herein are not to be limited in scope by the specific embodiments herein disclosed, since these embodiments are intended as illustration of several aspects of the disclosure.

Any equivalent embodiments are intended to be within the scope of this disclosure. Indeed, various modifications of the embodiments of the invention in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description. Such modifications are also intended to fall within the scope of the appended claims.

All publications, including non-patent literature (e.g., scientific journal articles), patent application publications, and patents mentioned in this specification are incorporated by reference as if each were specifically and individually indicated to be incorporated by reference.

What is claimed is:

1. A touch sensor comprising:

a substrate;

a plurality of first conductive lines supported by the substrate;

a plurality of blocks of piezoelectric material supported by the conductive lines;

a plurality of blocks of sensing material each supported by a block of the blocks of piezoelectric material;

one or more electrical contacts each supported by a block of the blocks of sensing material;

a plurality of second conductive lines respectively electrically connected to an electrical contact of the one or more electrical contacts on a respective block of sensing material on a first conductive line of the conductive lines and electrically connected to an electrical contact of the one or more electrical contacts on another respective block of sensing material on the first conductive line; and

the sensing material to sense a change in capacitance between the first conductive lines and the second conductive lines when a conductor is located near the first or second conductive lines and the piezoelectric material to sense a force applied to the sensing material;

wherein the first conductive lines are in a first direction and the second conductive lines are in a second direction substantially orthogonal to the first direction, and the first conductive lines, the second conductive lines and the sensing material define an array of physically separated transistors.

2. The touch sensor of claim 1, wherein:
the piezoelectric layer comprises AlN; and
the semiconductor layer is selected from the group consisting of one or more of ZnO, InGaZnO, Al(x)In(1−x)N and InN, in any combination.

3. The touch sensor of claim 1, wherein the sensing material includes forming material selected from the group consisting of one or more of ZnO, GaN, InN and AlInN, in any combination.

4. The touch sensor of claim 1, wherein:
the plurality of first conductive lines comprises indium tin oxide; and
the plurality of second conductive lines further comprises indium tin oxide.

5. The touch sensor of claim 1, further comprising a dielectric layer over the first conductive lines and the second conductive lines.

6. A method comprising:
forming a plurality of first conductive lines in a first direction on, or at least partially in, a substrate;
forming a plurality of blocks of piezoelectric material on each of the first conductive lines;
forming a block of sensing material on each of the blocks of piezoelectric material;
forming one or more electrical contacts on each block of sensing material;
forming a plurality of second conductive lines in a second direction substantially orthogonal to the first direction, the plurality of second conductive lines respectively electrically connected to an electrical contact of the one or more electrical contacts on a respective block of sensing material on a first conductive line of the conductive lines and electrically connected to an electrical contact of the one or more electrical contacts on another respective block of sensing material on the first conductive line; and
the sensing material to sense a change in capacitance between the first conductive lines and the second conductive lines when a conductor is located near the first or second conductive lines and the piezoelectric material to sense a force applied to the sensing material;
wherein the first conductive lines, the second conductive lines and the sensing material define an array of physically separated transistors.

7. The method of claim 6, wherein forming the sensing material further comprises:
forming the piezoelectric layer comprising AlN; and
forming the semiconductor layer selected from the group consisting of one or more of ZnO, InGaZnO, Al(x)In(1−x)N and InN, in any combination.

8. The method of claim 6, wherein forming the sensing material further comprises forming the sensing material using a material selected from the group including one or more of ZnO, GaN, InN and AlInN, in any combination.

9. The method of claim 6, wherein:
forming the plurality of first conductive lines further comprises forming the plurality of first conductive lines comprising indium tin oxide; and
forming the plurality of second conductive lines further comprises forming the plurality of second conductive lines comprising indium tin oxide.

10. The method of claim 6, further comprising forming a dielectric over the first conductive lines and the second conductive lines.

11. A touch-sensitive display comprising:
a display; and
a touch sensor in the display, the touch sensor comprising:
a substrate;
a plurality of first conductive lines on, or at least partially in, the substrate;
a plurality of blocks of piezoelectric material situated on each of the conductive lines;
a block of sensing material on each of the blocks of piezoelectric material;
one or more electrical contacts on each block of sensing material;
a plurality of second conductive lines respectively electrically connected to an electrical contact of the one or more electrical contacts on a respective block of sensing material on a first conductive line of the conductive lines and electrically connected to an electrical contact of the one or more electrical contacts on another respective block of sensing material on the first conductive line; and
the sensing material to sense a change in capacitance between the first conductive lines and the second conductive lines when a conductor is located near the first or second conductive lines and the piezoelectric material to sense a force applied to the sensing material;
wherein the first conductive lines are in a first direction and the second conductive lines are in a second direction substantially orthogonal to the first direction, and the first conductive lines, the second conductive lines and the sensing material define an array of physically separated transistors.

12. The touch-sensitive display of claim 11, wherein:
the piezoelectric layer comprises AlN; and
the semiconductor layer is selected from the group consisting of one or more of ZnO, InGaZnO, Al(x)In(1−x)N and InN, in any combination.

13. The touch-sensitive display of claim 11, wherein the sensing material includes forming material selected from the group consisting of one or more of ZnO, GaN, InN and AlInN, in any combination.

14. The touch-sensitive display of claim 11, wherein:
the plurality of first conductive lines comprises indium tin oxide; and
the plurality of second conductive lines further comprises indium tin oxide.

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